Climatology of Large-Scale Traveling Ionospheric Disturbances Observed with 14 MHz Amateur Radio Using a Novel Automated Detection Technique

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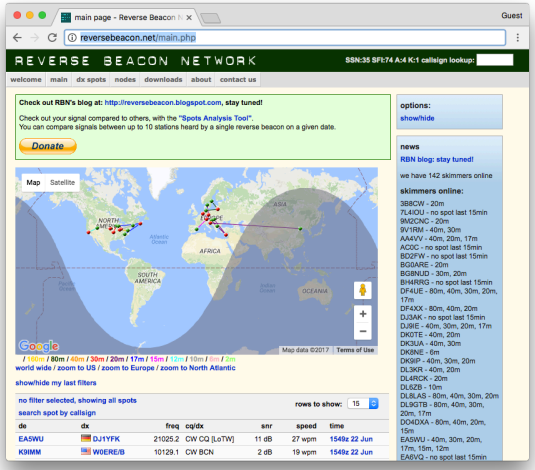
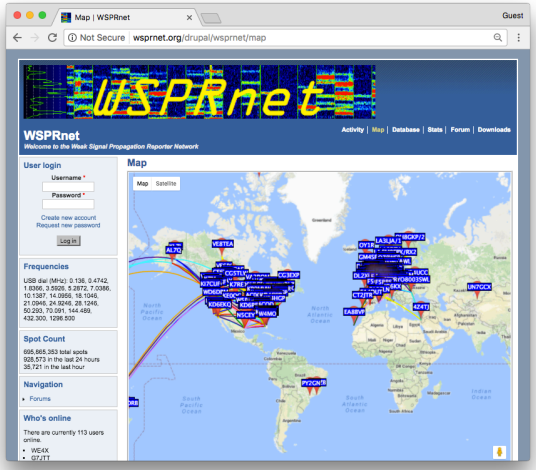
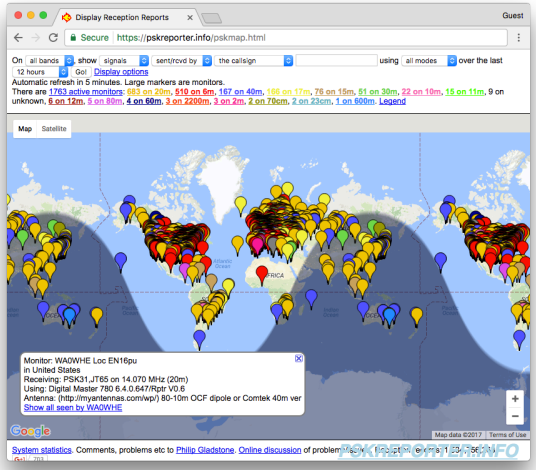
Amateur Radio Observation Networks



Reverse Beacon Network (RBN)
reversebeacon.net



WSPRNet
wsprnet.org

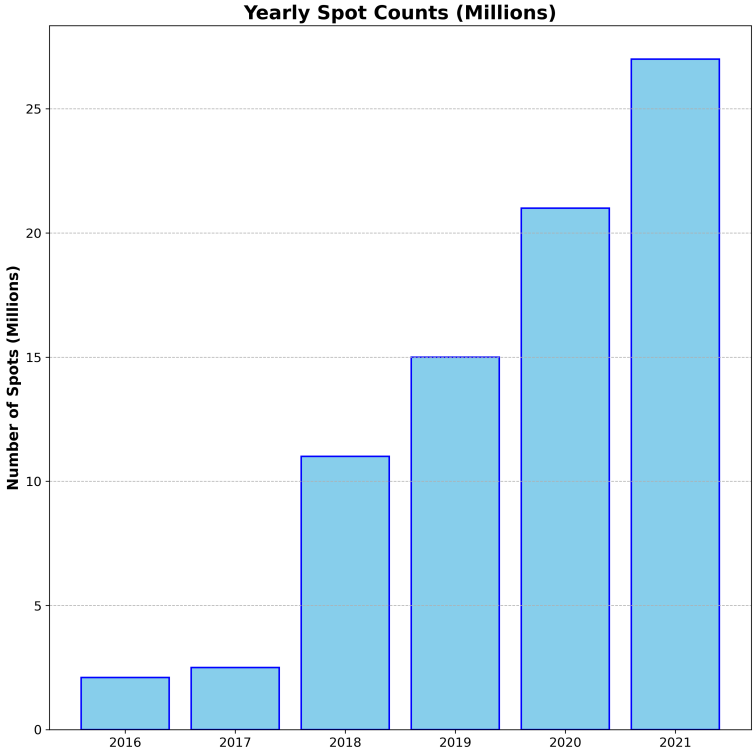


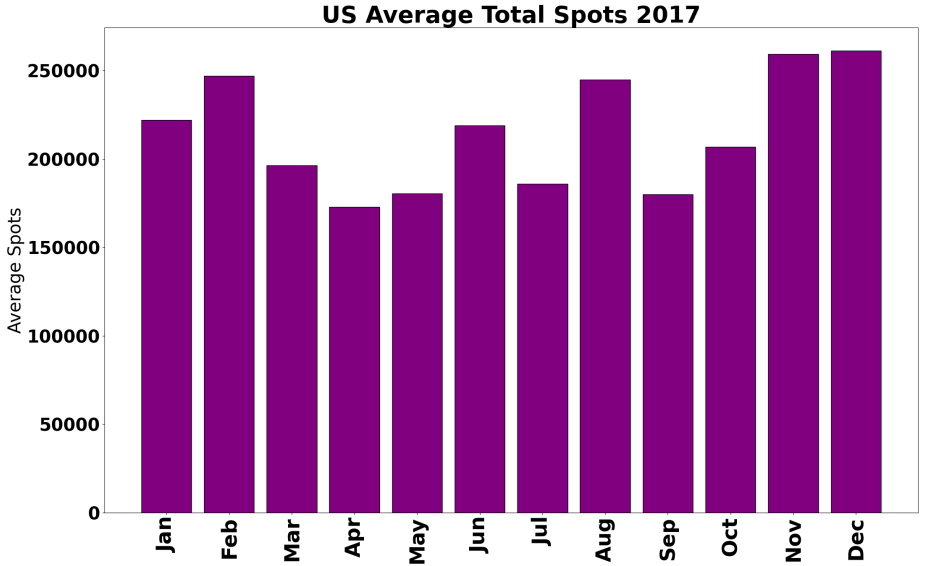
PSKReporter
pskreporter.info

- Quasi-Global
- Amateur community run
- Unique & Quasi-random geospatial sampling

- Data back to 2008 (A whole solar cycle!)
- Available in real-time!

Data Sources





Traveling Ionospheric Disturbances

TIDs are Quasi-periodic Variations of F Region Electron Density

Affects radio wave propagation.

Large Scale (LSTID)

- λ_h > 1000 km
- 30 < *T* [min] <180
- Often Auroral Electrojet Enhancement, Particle Precipitation

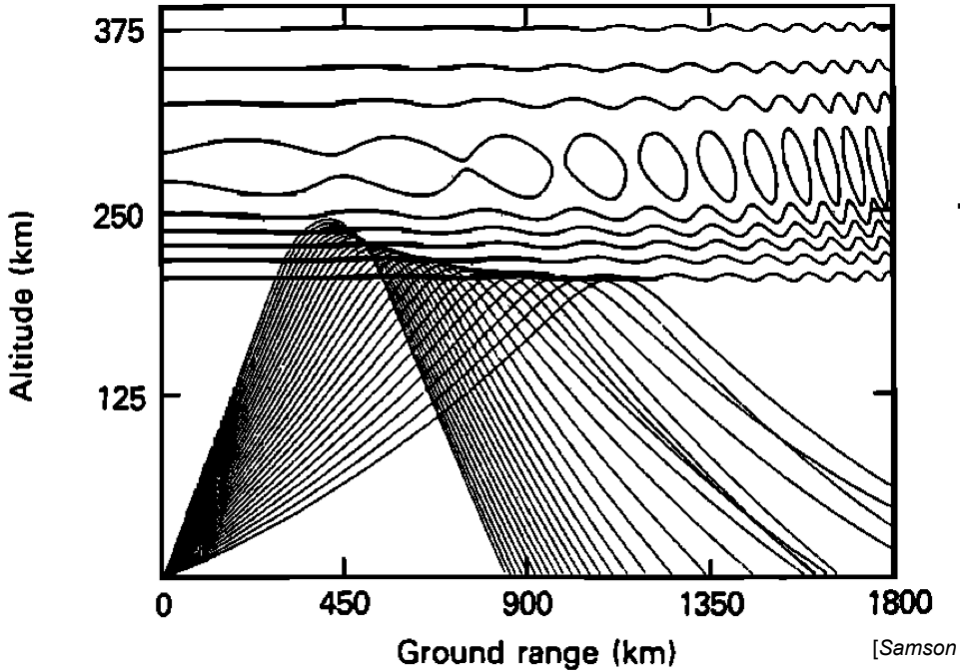
Observable by SuperDARN, GPS, and Ionosondes.

Low geographical coverage of existing instruments.

Often associated with Atmospheric Gravity Waves

[*Francis*, 1975; *Hunsucker* 1982; Ogawa et al., 1967; *Ding* et al., 2012; *Frissell et al.*, 2014; 2016]

Traveling Ionospheric Disturbances

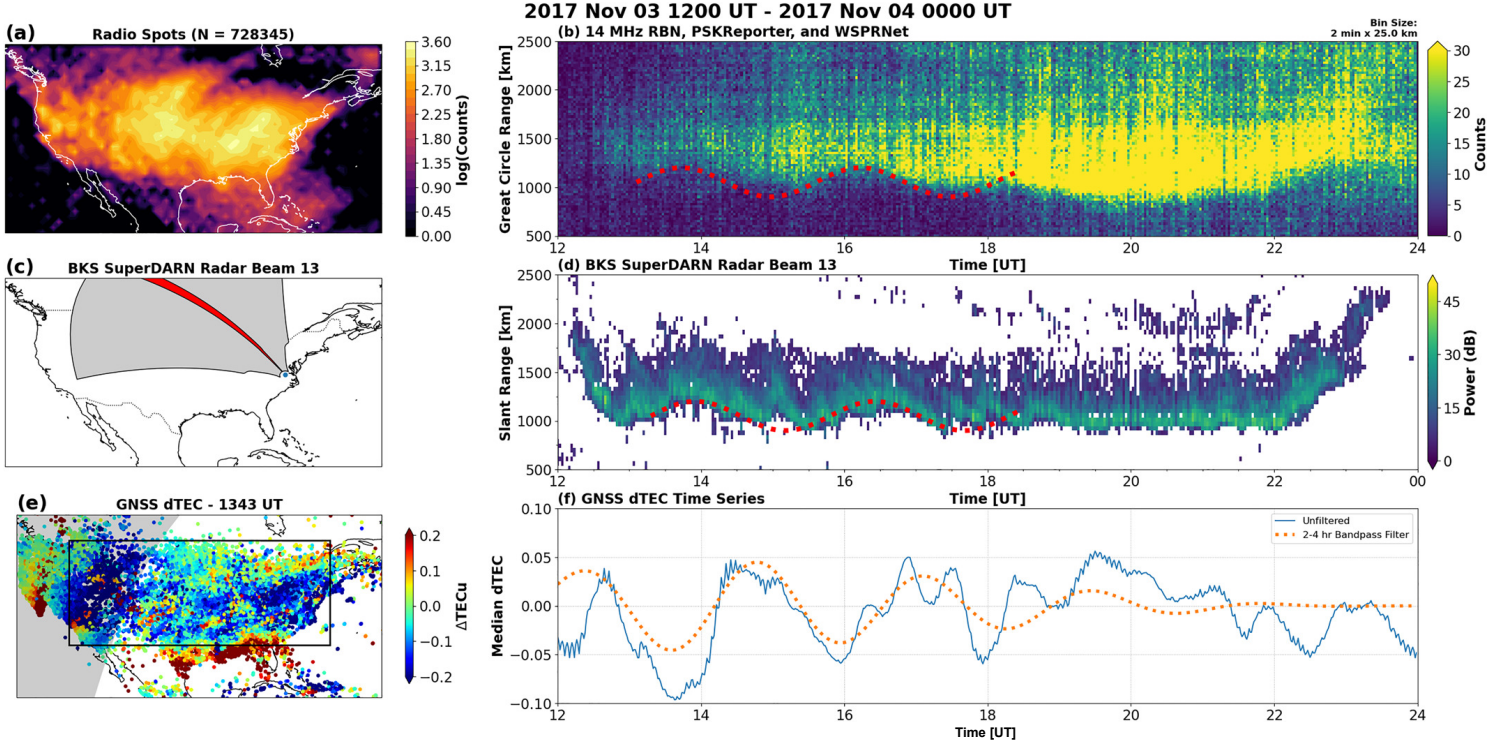


[*Samson et al.*, 1990]

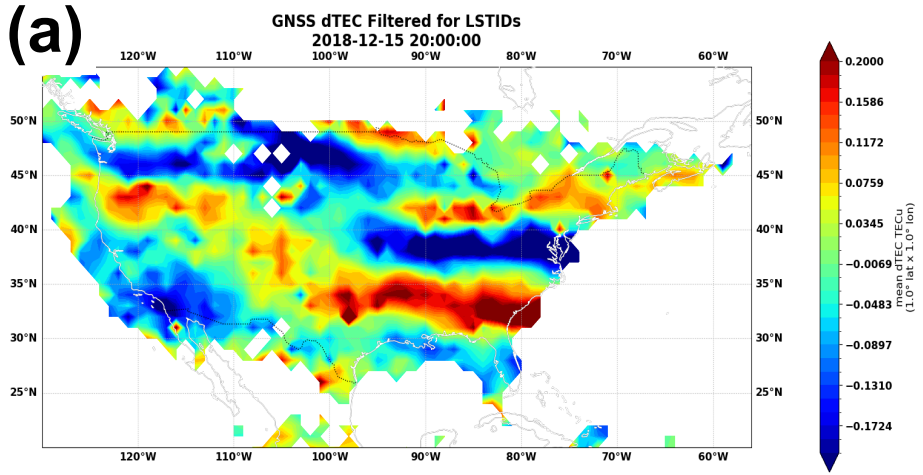
TIDs are a type of HF Fading

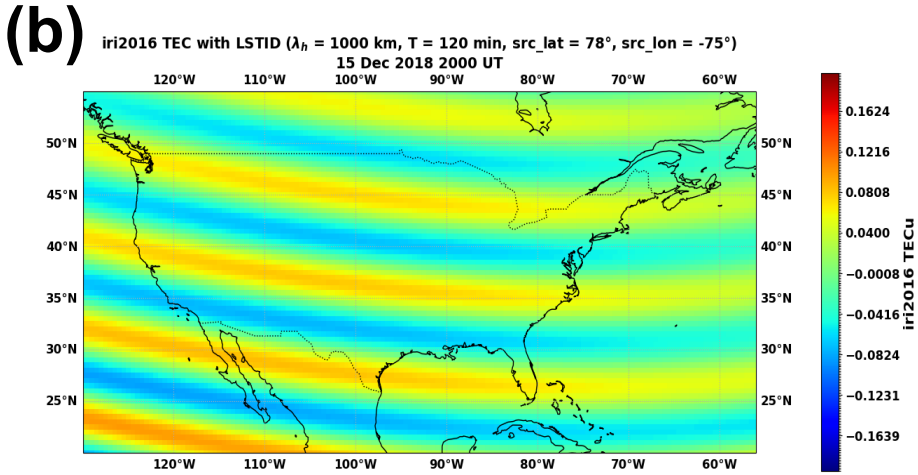
Amateur Radio Visualization

https://doi.org/10.1029/2022GL097879



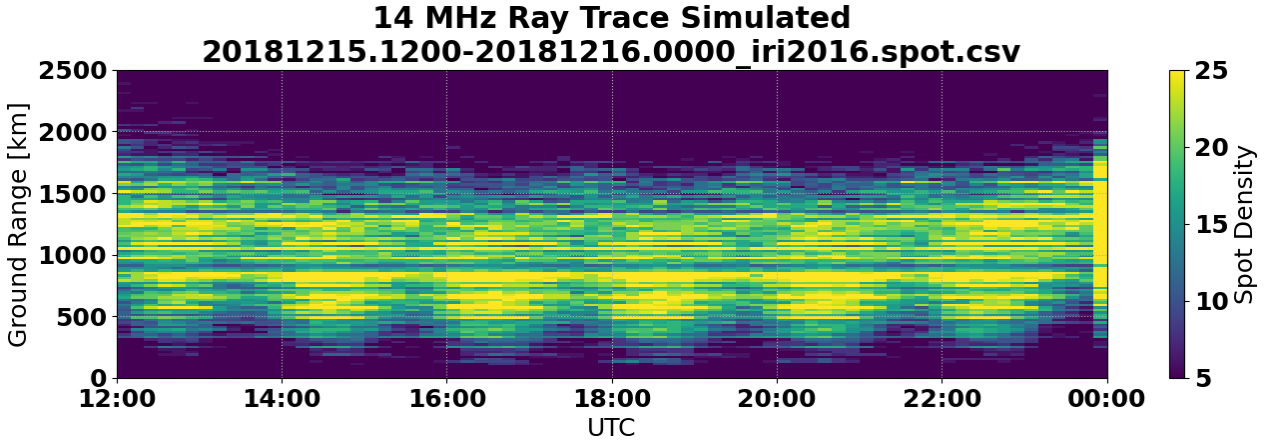
Amateur Radio LSTID Raytrace Modeling





- **Figure a** shows GNSS dTEC observations filtered for LSTIDs (*Derghazarian et al.*, 2023) at 2000 UTC on 15 Dec 2018.
- **Figure b** shows IRI2016 (*Bilitza et al.*, 2011; *Hirsch and Ilma*, 2024) perturbed with a radially propagating sinusoidal LSTID with $\lambda_h = 1000$ km, $T = 120$ min from source (78° N, 75° W).

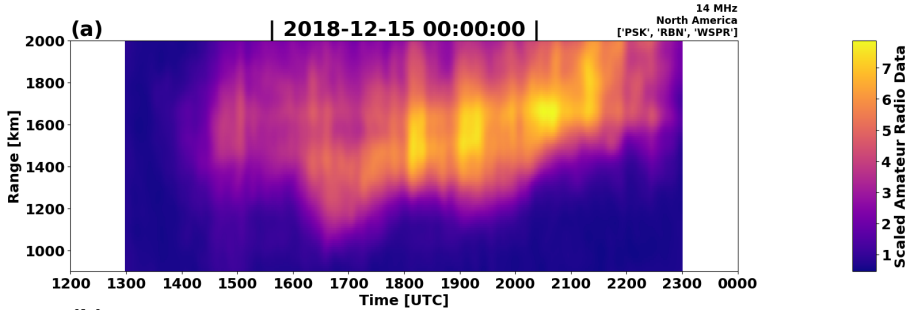
Amateur Radio LSTID Raytrace Modeling



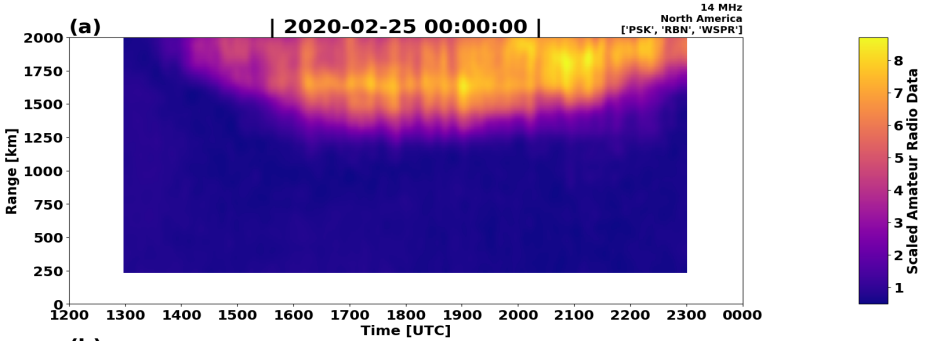
- Operating frequency: 14 MHz; Ray elevations 2° to 62° in 0.5° steps.
- Radio link considered successful if a ray was +/- 50 km from receiver range.
- Figure 3 shows a Range-Time heatmap of successful communications over the simulated time period.

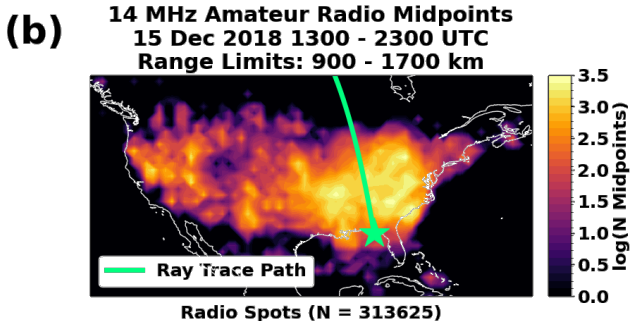
•From the WSPRNet, PSKReporter, and RBN amateur radio observations, there were 11.2 million possible TX-RX paths reported with paths < 3000 km and midpoints over CONUS on 15 Dec 2018.
•We conducted 2D ray traces over randomly selected 3000 TX-RX paths every 10 min from 12 to 24 UTC.

Amateur Radio Visualization



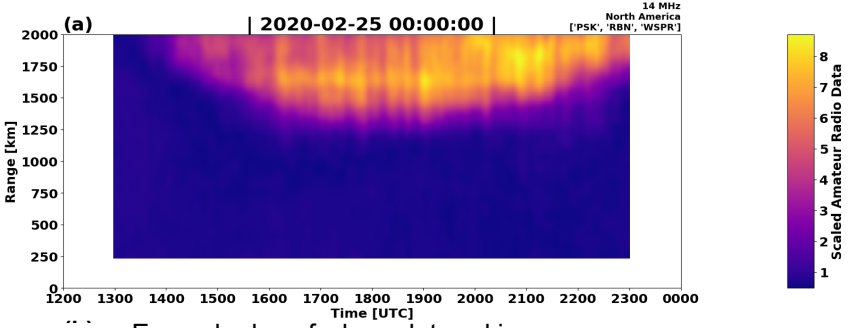
Amateur radio WSPR, PSKReporter, and RBN observations from 15 Dec 2018, a day with significant LSTID activity. Data are first gridded into 10 km x 1 min bins



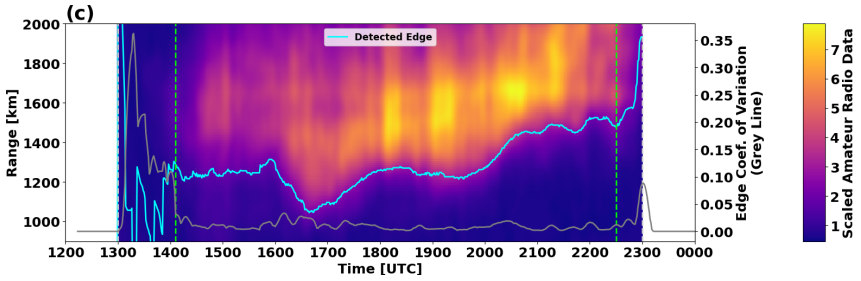

(b)
14 MHz Amateur Radio Midpoints
15 Dec 2018 1300 - 2300 UTC
Range Limits: 900 - 1700 km
Ray Trace Path
Radio Spots (N = 313625)
log(N Midpoints)

Heatmap of 14 MHz amateur radio communications midpoints with ground ranges of 900 - 2000 km for 1300-2300 UTC.

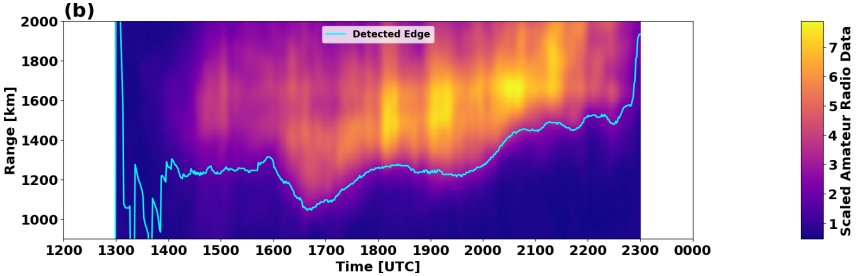
Automated Detection Algorithm



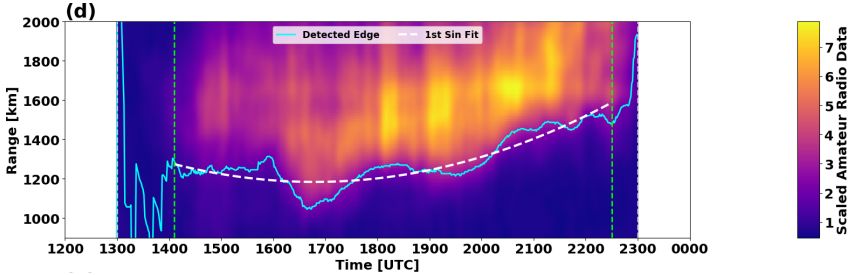
Example day of why a detrend is necessary.



A 15 min rolling coefficient of variation $CV = \sigma/\mu$ is computed for use as a quality parameter. The largest contiguous period where $CV < 0.5$ between 1330 and 2230 UTC is selected (vertical green dashed lines in Figure 1b).

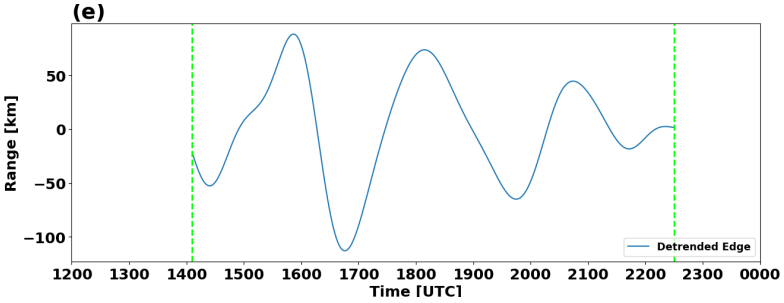


After re-scaling, smoothing, and thresholding, a column-wise percentile is used to identify the bottom edge first-hop skip distance.

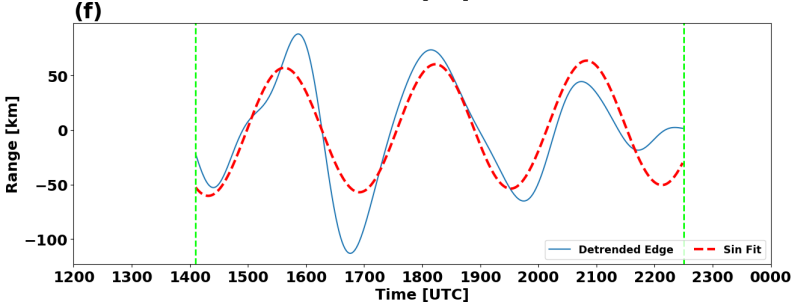


The raw detected edge within this time period is detrended using a least-squares best-fit second degree polynomial.

Automated Detection Algorithm



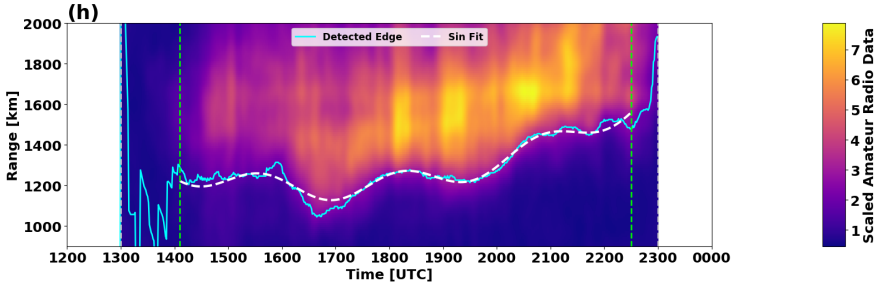
A $1 < T < 4.5$ hr bandpass filter is then applied.



This filtered, detrended result is curve-fit to a sinusoid to determine the LSTID oscillation amplitude and period.

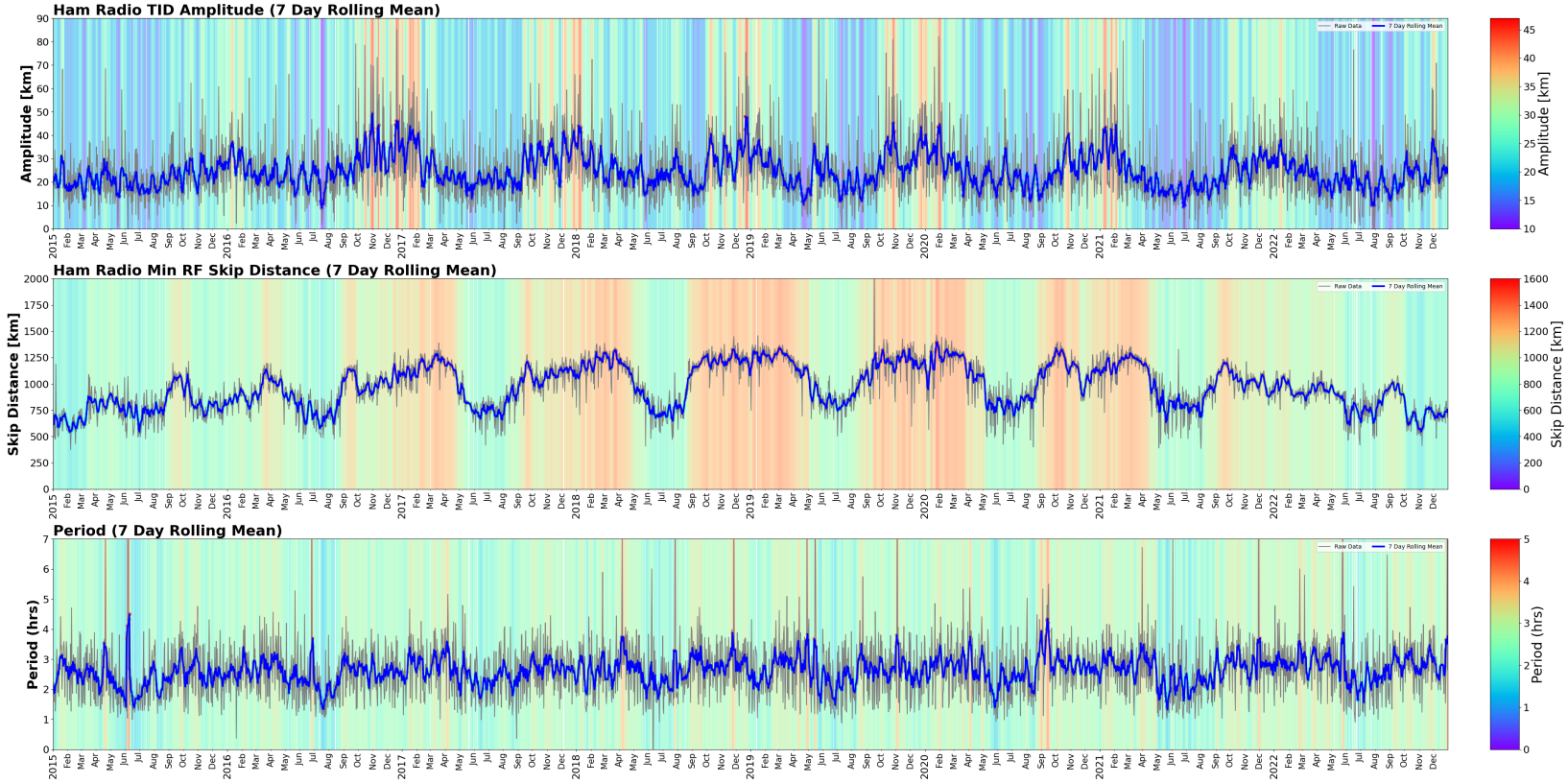
(g)

2nd Deg Poly Fit (Used for Detrending)	Sinusoid Fit
c_0: 4682.8	T_hr: 2.6
c_1: -0.1	amplitude_km: 57.9
c_2: 0.0	phase_hr: 0.6
r2: 0.81	offset_km: -20.5
	slope_kmph: 1.3
	r2: 0.74
	T_hr_guess: 2.5

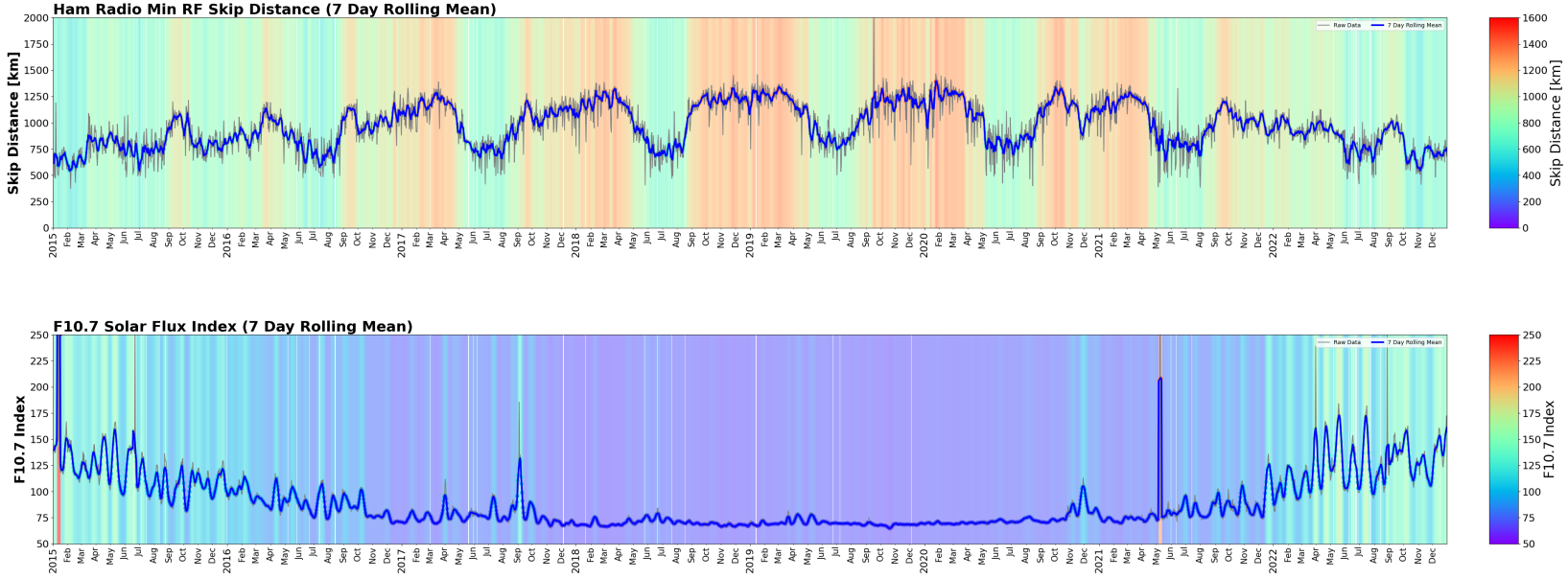


The white dashed line in Figure h shows the final, curve-fit sinusoid with the trend. Here, the amplitude is 57.9 km and period is 2.6 hr.

2015-2022 Climatology


Ham Radio TID Amplitude (7 Day Rolling Mean)
Amplitude [km]
Raw Data
7 Day Rolling Mean
Ham Radio Min RF Skip Distance (7 Day Rolling Mean)
Skip Distance [km]
Period (7 Day Rolling Mean)
Period (hrs)

2015-2022 Climatology


Ham Radio Min RF Skip Distance (7 Day Rolling Mean)
Skip Distance [km]
Raw Data
7 Day Rolling Mean
Skip Distance [km]
F10.7 Solar Flux Index (7 Day Rolling Mean)
F10.7 Index
Raw Data
7 Day Rolling Mean
F10.7 Index

Conclusions and Future Work

- LSTIDs were mostly observed during the winter months, with a decline during the spring and fall, and occasional enhancements during the summer
- Overall increase in the minimum skip distance from 2015 to 2020 with a decline starting in 2021 consistent with the solar cycle.
- Automated detection method is consistent each year when observing seasonal patterns.
- Available spot data from RBN, WSPRNet, and PSK Reporter have been growing significantly over the years.
- Current issues with this edge detecting algorithm are that it was optimized for the years 2017-2019. Further work is being done to adjust the algorithm to be more efficient for all of the available data.
- Further development of the automated technique is required to help with curve fitting accuracy.

References and Acknowledgments

Frissell, N. A., Baker, J. B. H., Ruohoniemi, J. M., Gerrard, A. J., Miller, E. S., Marini, J. P., West, M. L., and Bristow, W. A. (2014), Climatology of medium-scale traveling ionospheric disturbances observed by the midlatitude Blackstone SuperDARN radar, J. Geophys. Res. Space Physics, 119, 7679–7697, doi:10.1002/2014JA019870.

Frissell, N. A., Baker, J. B. H., Ruohoniemi, J. M., Greenwald, R. A., Gerrard, A. J., Miller, E. S., and West, M. L. (2016), Sources and characteristics of medium-scale traveling ionospheric disturbances

Francis, S. H. (1975), Global propagation of atmospheric gravity waves: A review, J. Atmos. Terr. Phys., 37, 1011–1054, doi:10.1016/0021-9169(75)90012-4.

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We would also like to make a special mention to Dr. Lynn Harvey of the University of Colorado Boulder for her contribution to this study and for facilitaing the MERRA-2 data utilized in this climatology.

Ham Radio Citizen Science Investigation

HamSCI, the Ham Radio Science Citizen Investigation, is a platform for the publicity and promotion of projects that are consistent with the following objectives:

- Advance scientific research and understanding through amateur radio activities.
- Encourage the development of new technologies to support this research.
- Provide educational opportunities for the amateur community and the general public.

HamSCI serves as a means for fostering collaborations between professional researchers and amateur radio operators.

Projects such as the Reverse Beacon Network, WSPRNet, PSKReporter, DX Cluster, ClubLog, and more are generating big data sets that could provide useful observations of the Earth's ionosphere and related systems.